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REPORT ON THE ACCIDENT AT THE "THREE MILE ISLAND" NUCLEAR POWER STATION

INTRODUCTION

Following the accident which occurred at the "Three Mile Island" nuclear power plant in the US, the Commission of the European Communities decided, as an initial measure, to send two officials to the US in order to obtain information on the spot.

Several Member States and other countries had also thought it necessary to have representatives at the scene of the accident. As a result, Belgium, France, Italy, the Netherlands, the Federal Republic of Germany and the United Kingdom were represented.

The Nuclear Regulatory Commission, the Federal organization responsible for nuclear safety, was anxious to make public as soon as possible information concerning the course of the accident. The Office of International Programmes, in particular, endeavoured to provide the foreign visitors with preliminary information as this became available.

Briefing sessions arranged with NRC experts on specific aspects of the accident made it possible to exchange opinions and clarify a number of points.

On 5 April 1979, the NRC arranged a visit to the actual site during which Mr. Harold Denton, principal NRC official at the power station, gave an account in Middletown, the locality closest to the power plant, of the situation in the plant at that moment.

The report on the accident and the associated events is based on the preliminary written and oral information supplied by the NRC and on the information contained in the "NUREG" reports published by the NRC in respect of the power plant in question. It was possible to consult these reports at the Public Document Room in Washington, DC.

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In view of the preliminary nature of the information, the contents of this report should likewise be regarded as provisional. In particular, its conclusions should be reviewed in the light of the results of the detailed examination concerning the data of the accident.

Independently of the analysis of the accident data by the NRC itself, an eleven-man commission has been set up by President Carter and will produce a report within six months.

THE THREE MILE ISLAND NUCLEAR POWER STATION

General Plant Description

The Three Mile Island power station is situated in the south-eastern part of the state of Pennsylvania. The station is on an elongated island in the Susquehanna river, on the eastside. The closest community is Middletown at a distance of about 3 miles (5 km). The distance to Harrisburg is just over 10 miles (16 km).

The station is owned by Metropolitan Edison Company, Jersey Central Power and Light Company and Pennsylvania Electric Company. All three owner companies are subsidiaries of General Public Utilities Corporation.

The Three Mile Island power station consists of two generating units, both equipped with pressurized water reactors of Babcock and Wilcox design. Unit 1 has a net capacity of 792 MWe, Unit 2 a net capacity of 880 MWe.
The accident occurred in Unit 2, on 28 March 1979, while Unit 1 was shut-down for yearly maintenance.

The construction of TMI Unit 2 started more than 10 years ago. The reactor was made critical on 28 March 1978 and the unit started to deliver electricity to the network on 30 December 1978.

DESCRIPTION OF THE ACCIDENT

At about 4.00 a.m. on 28 March 1979, the secondary (non nuclear) cooling system of the Three Mile Island power station suffered a malfunction. This system normally pumps water through the plant's steam generators where the water turns to steam which then flows to turn a turbine generator. The steam is then condensed back to water, which is pumped by a condensate pump through a clean up system, through a feedwater pump, and finally back to the steam generator, and flow continues around this loop.

A malfunction in the main feedwater system caused the feedwater pump to cut out, which in turn caused the turbine generator to shutdown and stop generating electricity. Since the steam generators were not removing heat due to the stoppage of feedwater flow, the reactor coolant system pressure increased and the pressurizer relief valve opened to reduce reactor pressure. The reactor shutdown automatically by the rapid insertion of the plant's control rods as designed, and the nuclear chain reaction stopped leaving behind principally residual, or decay, heat. These events all occurred within the first 30 seconds following the initial event.

Up to this point, this sequence is normal given the initiating event and plant response was as expected, and the auxiliary feedwater system should start-up and deliver secondary coolant to the plant's two steam generators to remove heat. In addition, the pressurizer relief valve should close as reactor pressure decreases.

All three of the auxiliary feedwater pumps are reported to have started but were unable to deliver flow because their flow paths were blocked by closed valves. Auxiliary feedwater flow was established through the opened valved about eight minutes later. In addition, the pressurizer relief valve failed to close and therefore allowed the reactor coolant system pressure to continue to decrease.

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As the reactor pressure reached a preset value (112 kg/cm^2), the plant's Emergency Core Cooling System (ECCS) started as designed and began to inject cold water into the reactor. At this point an indication of a rapidly rising pressurizer level apparently led the plant operators to terminate the ECCS flow. The Three Mile Island incident had been underway for 11-12 minutes.

Between about 1 and 2 hours into the transient, the operators turned off the four large pumps which circulate the reactor coolant through the reactor. It is following this action that the severe damage to the nuclear fuel began. For the next several hours there was a very large temperature difference across the reactor core indicating little flow of coolant through the core.

It is thought that the high temperature in the reactor core led to swelling and bursting of a number of fuel tubes, causing the release of fission products to the primary coolant. This is also the period when the zirconium-water reaction producing hydrogen, must have taken place. The hydrogen collected in the top of the reactor vessel and this gas bubble caused problems in the circulation of the primary coolant.

During this several hour period, when fuel damage was occurring, primary coolant from the reactor primary coolant system was being discharged to the reactor containment floor from flow out of the pressurizer relief valve and through the drain tank. Part of this coolant was automatically pumped from the reactor containment building floor to tanks in the auxiliary building. The tanks overflowed permitting radioactivity to be vented from the auxiliary building. This discharge was secured in about 40 minutes. The reactor containment was sealed (isolated) at about 9.00 a.m.

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Through the afternoon and early evening of 28 March 1979, the licensee isolated the stuck open relief valve and tried to depressurize the reactor coolant system sufficiently to be able to turn on the residual heat removal system. Since his attempt failed, it was decided to repressurize the system.

After repressurization (about 8.00 p.m.) one of the main reactor coolant pumps in loop A was restarted and flow through the reactor core was established. Heat was being transferred out of the reactor through the steam generator while using the condenser. The primary system was maintained at a pressure of approximately 70 kg/cm^2 and a temperature of 138 $^\circ C$.

Reactor cooling has essentially been in this form since that time, while hydrogen from the primary coolant system was evacuated by degassing. This was brought about by transferring, gradually, the hydrogen to the pressurizer and venting it in a controlled manner to the containment. The other efforts have mainly been devoted to maintaining this condition while a series of analyses have been conducted and while measurements have been taken to confirm a variety of parameters. These efforts have been directed towards preparing for the next steps in the cooldown process.

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ACTIVITY RELEASED AND ENVIRONMENTAL EXPOSURE

Discharges to the atmosphere during the accident consisted essentially of radioactive noble gases although small amounts of iodine-131 and caesium-137 were also released.

Liquid radioactive effluents were released, deliberately, into the Susquehanna River. These releases were probably within the limits cited in the Technical Specifications for the plant.

US officials estimate the average individual dose in a 50 mile radius around the plant, received during the first week after the accident, to be 1.1 mrem. The maximum external whole body dose to a hypothetical individual staying permanently in the open air at the most exposed point accessible to the public would have been less than 100 mrem. For comparison, the dose limit for a member of the population is 500 mrem per year and natural background is of the order of 100 mrem per year.

Analysis of air and milk samples showed iodine-131 to be present in a few cases and, in milk, traces of caesium-137 were occasionally detected; the results for water, soil and vegetation were below the limit of detection. In all cases the peak concentrations present corresponded to potential doses of less than 5 % of the annual dose limits.

Up to 4 April, 3 members of the plant personnel received doses of about 4 rem; other personnel received lower doses. The maximum permissible whole body dose for occupational exposure is 5 rem/year.

From the above it appears that the radiation doses received as a result of the accident by the population living around the TMI plant and by plant personnel cannot be considered as significant from the health point of view.

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EMERGENCY PLANNING AND MEASURES

The State of Pennsylvania has two organizations for emergency planning :

- The Pennsylvania Emergency Management Agency (PEMA), which has the task of implementing the protective measures for the population as decided by the Governor.

- The Radiological Assessment Branch of the Environmental Resources Department, which recommends protective measures to the Governor.

The PEMA has 4 country Emergency Operation Centers (EOC), of which one is in Harrisburg, to which it communicates the orders or recommendations of the Governor. The EOCs are responsible for alerting the population.

The accident started on 28 March at 4.00 a.m. At 7.00 a.m. the licensee declared an internal site emergency; a general emergency was declared at 7.30 a.m. when a high level of radioactivity was detected in the containment building. However, since during the first days the dose readings around the plant remained low, no off-site intervention measures were taken.

On Friday morning, 30 April at 8.40 a.m., venting of one of the radioactive waste gas decay tanks through the stack produced a radiation dose rate above the stack of 1.2 R/hr (later corrected to 0.6 R/hr). As a result of this, NRC, not having been informed by the licensee of his intention to vent the tanks and hence being unaware of the origin of the activity release, suggested to the Governor of Pennsylvania that pregnant women and pre-school children in an area of five miles around the plant should be evacuated. At noon the Governor gave this recommendation (not an order) to the population. The PEMA with the aid of the civil defense warned Middletown residents with sound trucks. (This was the only protective measure taken by the Governor). However, everybody treated it as an order. As a result of this, nearly the whole population of Middletown, 3.5 miles from the plant, left the area; 23 schools were closed. During the weekend of 31 March - 1 April, as an explosion of the hydrogen bubble in the reactor vessel of the TMI plant was feared, plans were drawn

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up to evacuate the entire region up to 25 miles around the site. Such an order was however never given. The authorities feared that an evacuation could cause an immense traffic jam; nevertheless, thousands of people (estimates range from 80,000 to 200,000) voluntarily left their homes during the course of the weekend.

Problems encountered during the Emergency

According to statements made by NRC officials during briefings, the following problems were encountered :

- The State and local authorities were not sufficiently prepared for such an emergency. (In 1974 Metropolitan Edison wrote to the Middletown borough officials that "... even the worst possible accident postulated by the AEC would not require evacuation of the borough of Middletown ... it can be seen that it is unnecessary to have specific evacuation routes specified ...").

- The recommendation for a selective evacuation endorsed by the Governor had unexpected consequences. Other people thought, "Why not me ?". As a result more than 50 % of the population in the 5-mile zone (25,000 people) left the area and in the 25 mile zone (650,000 people) at least 10 % (some say 30 %).

- The Department of Health, Education and Welfare (H.E.W.) has fixed Protective Action Guides and has recommended the distribution of a thyroid blocking agent, potassium iodide (KI), to the population in case of radioactive iodine releases. At the time of the accident no KI was available (H.E.W. had just started contacting KI manufacturers). Two days after the accident 50,000 vials of KI (in liquid form) were shipped to Middletown. However, as little iodine was in practice discharged to the environment, no use was made of it.

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- The environmental monitoring was carried out by several organizations

  - State of Pennsylvania
  - Department of the Environment
  - Environmental Protection Agency
  - NRC

  During the first 3 days there were very long delays in obtaining monitoring results. Some samples were received several days after collection; many were received without reference to sampling location or time (both extremely important for deciding on protective measures).

- In the beginning there were many communication problems between the plant operator, NRC and the Government. Later permanent open telephone lines between the various organizations involved were installed, with servicemen from the telephone company permanently in attendance.

CONCLUSIONS

In a preliminary analysis the Nuclear Regulatory Commission has identified the following six potential failures which have led to the core damage and activity releases in the TMI plant.

1. At the time of the initiating event, loss of feedwater, both of the auxiliary feedwater trains were valved out of service.

2. The pressurizer electromatic relief valve, which opened during the initial pressure surge, failed to close when the pressure decreased below the actuation level.

3. Following rapid depressurization of the pressurizer, the pressurizer level indication may have lead to erroneous inferences of high level in the reactor coolant system. The pressurizer level indication apparently led the operators to prematurely terminate high pressure injection flow, even though substantial voids existed in the reactor coolant system.

4. Because the containment does not isolate on high pressure injection (HPI) initiation, the highly radioactive water from the relief valve discharge was pumped out of the containment by the automatic initiation of a transfer pump. This water entered the radioactive waste treatment system in the auxiliary building where some of it overflowed to the floor. Out-gassing from this water and discharge through the auxiliary building ventilation system and filters was the principal source of the offsite release of radioactive noble gases.

5. Subsequently, the high pressure injection system was intermittently operated attempting to control primary coolant inventory losses through the electromatic relief valve, apparently based on pressurizer level indication. Due to the presence of steam and/or non-condensible voids elsewhere in the reactor coolant system, this led to a further reduction in primary coolant inventory.

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6. Tripping of reactor coolant pumps during the course of the transient, to protect against pump damage due to pump vibration, led to fuel damage since voids in the reactor coolant system prevented natural circulation.

Following this analysis NRC has issued a list of actions to be taken by all licensees of operating light water reactors. This list of actions to be taken has also been transmitted to operators of light water reactors in Europe.

Of the six potential failures, one (1) is a human error, one (2) is purely mechanical failure and one (4) a design failure. Three (3) (5) (6) of the failures can be seen as combinations of mechanical failures and human errors.

The most important failure, which is at the basis of the whole sequence of events, is that the auxiliary feedwater system of the steam generators was valved out. The operation of the reactor under these circumstances is in flagrant violation of the NRC regulations laid down in the technical specifications of the plant (NUREG 0432-app. A Feb. 8/1978) which specify that : "Three independent steam generator emergency feedwater pumps and associated flow paths shall be OPERABLE ...." Without this violation the accident would not have occurred. Furthermore, the question remains why action to open the valves was taken only 8 minutes later.

The failure of the electromatic relief valve to close when the pressure decreased below the actuation level was a mechanical failure. There is no explanation yet for the fact that action to isolate this valve was only taken more than two hours after the start of the accident.

The premature termination of the high pressure core cooling injection seems to result from an erroneous level reading. The question whether other instrument data were available to the operators remains open.

On the basis of information available at the present time the erroneous level reading may be considered a mechanical failure. There may also be a design aspect related to this failure, as it remains unclear whether the level indicator was designed to work in the conditions of pressure variations and gas bubbles in the system as experienced during the accident.

At TMI the isolation of the containment building is initiated only by overpressure in the containment building (0.28 kg/cm^2) and this occurred only 5 hours after the beginning of the accident. In other designs the reactor building is also isolated when the emergency core cooling system starts to operate. If this had been the case at TMI, no highly radioactive primary water would have been pumped into the auxiliary building. This is a design failure which diminished the efficiency of the containment to perform its function of limiting activity release.

The intermittent operation of the emergency core cooling system was based on the reading of the level in the pressurizer. This probably erroneous reading is the one that lead to the premature termination of the high pressure injection and the comments that can be made concerning this failure are of the same nature as those related to the premature termination of the high pressure core cooling injection.

The stopping of the primary coolant pumps was based on the knowledge that natural circulation would be sufficient to cool the shut-down reactor. However, the tests which demonstrated this natural circulation cooling did not simulate the low pressure conditions during the accident nor did they account for the possible presence of gas bubbles in the primary system. The plant operators probably did not realize this difference in conditions.

In addition, the following preliminary comments can be made regarding the accident. They should be reviewed when more information becomes available.

Human Errors

- The human errors that occurred show that more attention must be paid to :

  1) the qualifications of plant operators; their expertise should be such that decisions such as the blocking of an important system in violation of the technical specifications would never come up for consideration.

  2) the inspection of nuclear installations; a strict and constant control by an independent body is of prime importance. NRC had already permanent inspection on some nuclear installations. It is probable that the programme for the dispatching of resident inspectors will be accelerated.

- At the outset of the accident and in the crucial hours that followed some difficult but important decisions had to be taken by the plant operator. Probably some of these were wrong. Therefore technical back-up teams which can be sent immediately to a plant in difficulty to assist the licensee in his decisions could be useful.

Design Failures

- Remote operation of the purge valves on the reactor vessel is not possible at TMI or any other light water reactor. The reason is that accidental opening of the valves could be the origin of a loss of coolant accident. This point should be re-examined in the light of the experience from the TMI accident. The remote operation of the purge valves could in this case have permitted the release of the hydrogen from the reactor vessel.

- Effluent monitoring in the stack through which the auxiliary building is vented seemed not to be working correctly. Since these detectors must give the ultimate information on the radiological risks for the

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environment and on the emergency measures to be taken, they should be reliable under all circumstances.

- The storage capacity of the liquid and gaseous waste collection tanks was much too small; during the accident they had to be emptied several times into the environment and new tanks had to be rushed to the site for liquid waste storage. Waste production during an accident should therefore be taken into account when designing the waste storage capacity.

Emergency Response Planning

The Pennsylvania State and local authorities were not sufficiently prepared to cope with an emergency of this kind. The accident has shown that particular attention must be given to emergency planning and preparedness, especially with regard to :

- reference accidents for which emergency plans must be worked out,
- setting of protective action levels,
- specific responsibilities of participating organizations,
- emergency equipment and personnel,
- communication systems,
- evacuation routes, reception centres,
- distribution of thyroid blocking agents (KI),
- environmental monitoring programmes and teams,
- training of personnel involved in emergency interventions.

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Radiological Consequences of the Accident

According to the survey results, doses received by members of the public as a consequence of the accident are low compared with the dose limits. The environmental contamination has also been minimal. Occupational exposure up to 4 April was still within the annual limits. Therefore from a health point of view the consequences of the accident can be considered as not significant.

Safety Evaluation

The TMI accident has shown that the safety systems have performed their function of limiting the releases of radioactivity to the environment to acceptable levels. However, it is also clear that the safety evaluation studies concerning the pressurized water reactors have not yet fully covered all the possible major occurrences. This is in particular the case for hydrogen formation by the zirconium-water reaction and hydrogen accumulation in the top of the reactor vessel, causing cooling problems and risk of explosion. The safety evaluation of PWR reactors will need to be reviewed and extended with respect to these problems.

Information

The US public appears to be rather well informed about nuclear energy and its risks. In general the reaction of the public, even during the more critical phases of the accident cannot be considered excessive. In addition opinion polls have shown that the attitude towards nuclear energy, which was rather positive, has not changed significantly as a result of the accident.

During the course of the accident the US authorities, and more particularly NRC, have shown continuous concern to make public all information which became available. This is particularly well demonstrated by the telex information which was made available by the US embassies. The NRC office of international programmes has also organized technical briefings and meetings for the benefit of foreign technicians.

This attitude of preparedness to share the available information is to be appreciated all the more in that NRC was particularly cautious with regard to the evaluation of what happened because of the far reaching implications any premature conolusions might have.